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HIDDEN ASSETS: Biodiversity Below-Surface

The Earth's soils and sediments are dynamic living interfaces that are habitats for millions of species.

To sustain the productivity of our lands, freshwaters and oceans,

it is essential to learn how these below-surface species provide vital ecosystem services and to integrate this knowledge into management and policy decisions.

Ecological and Earth Sciences in UNESCO

Below-surface biodiversity critical to life

Blind springtail.
Credit: Andrew R. Moldenke.

The below-surface biodiversity ranges from the 'invisible' bacteria, fungi, microbes, microscopic invertebrates to larger invertebrates such as ants, earthworms and termites in soils and crayfish, shrimps, mussels, worms and other organisms in freshwater and marine ecosystems.

Because the majority of soil and sediment biodiversity is hidden beneath lands, freshwaters and oceans, this species richness remains mostly unknown, poorly mapped, and rarely considered in management decisions. Yet, this vast biodiversity is critical to the well-being of all life, both below and above the surface, as it provides ecosystem services such as filtering air and water and regulating the global cycles of carbon, nitrogen, and phosphorus.

Worldwide degradation and destruction of soil and sediment habitats diminishes the biodiversity of below-surface and the associated above-surface biotic communities. Because the soils and sediments of fresh and marine waters are intertwined, effects on biodiversity in one habitat can affect the others. Losses of below-surface biodiversity result in cascading effects on ecosystem processes and services, increased societal costs, and widespread impacts on local and national economies.

Once these species and the services they provide for ecosystems and humans are lost, the damage will require long periods for remediation and restoration while loss of some species might be irreversible. In many cases, the broad scales of impact mean that active restoration is extremely costly and remediation may not even be possible. In order to ensure the long-term sustainability of soils and sediments and the biodiversity they support, identification and implementation of integrated management practices are urgently needed.

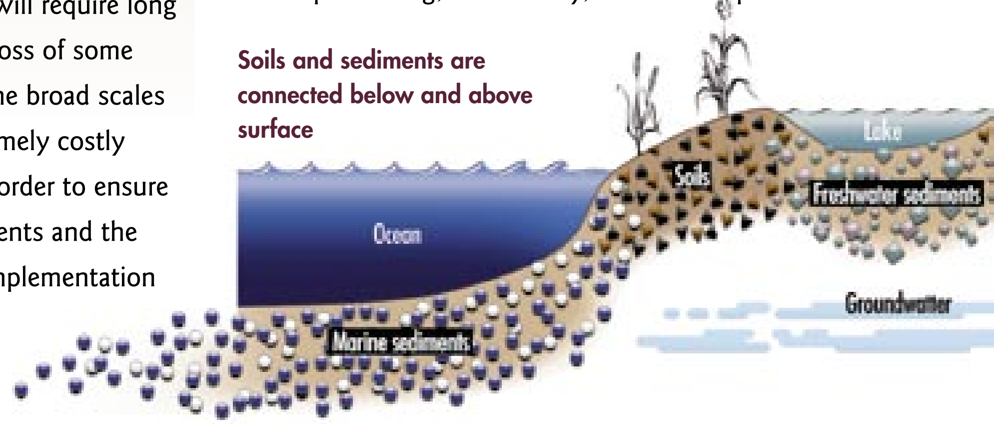
Soils, like sediments, vary in chemical and biological composition, sometimes within the length of a meter. Some regions have extremely productive, high fertility soils (e.g., the Nile Delta region), but other regions have soils underlain by permafrost, or very shallow and less productive soils. Because of the demand for food and fuel, and increasing global changes leading to degraded soils (e.g., desertification, droughts, floods), many regions are losing their productive lands. Although not represented in this map, marginal lands are increasingly being impacted, as well as sediments in lakes, streams, rivers and oceans.

Ecosystem services provided by below-surface biodiversity

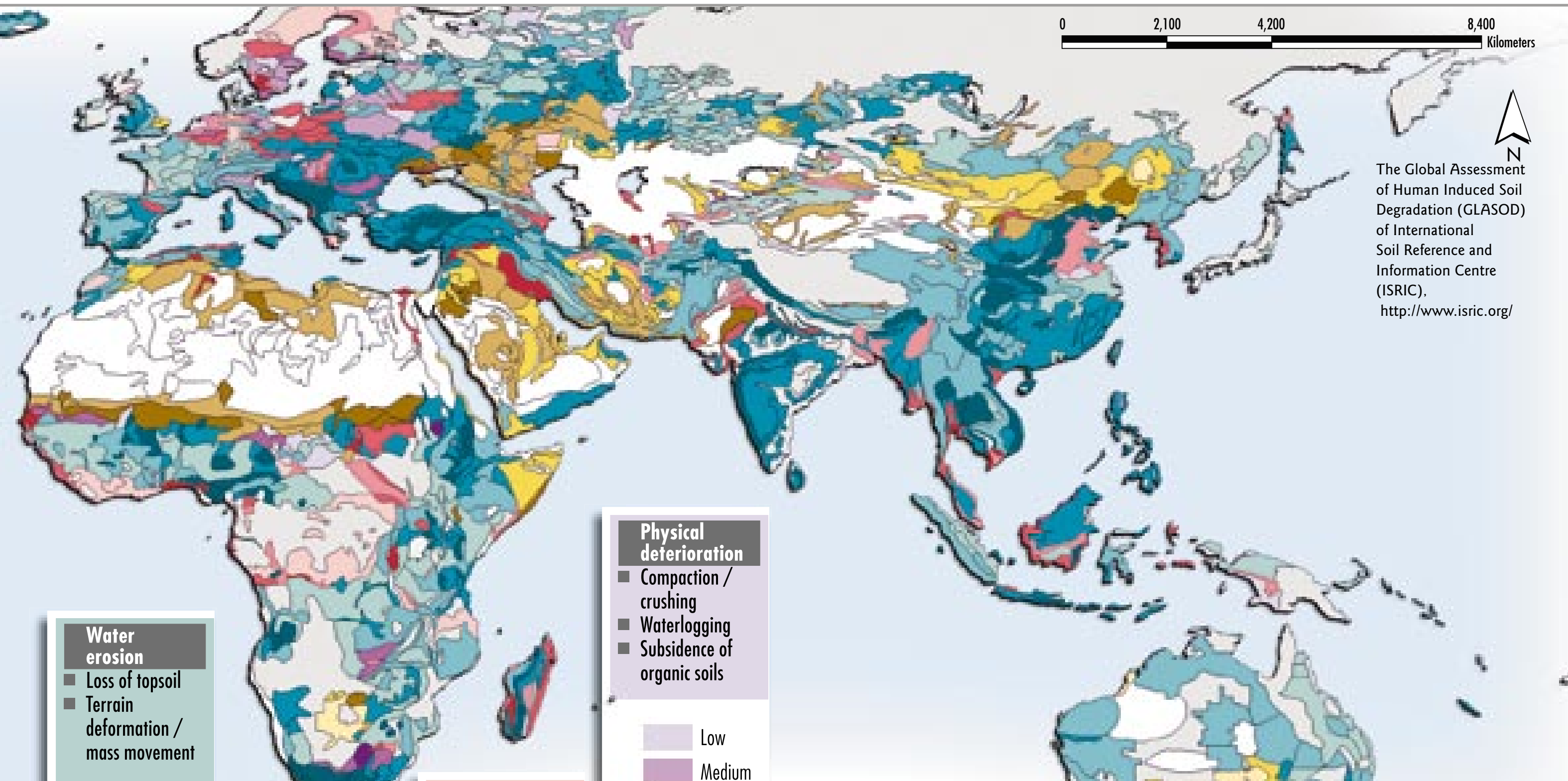
All sub-surface and above-surface organisms depend on soil and sediment biodiversity for food and habitat. Human health and well-being and national economies are largely based on the benefits provided by soils, freshwater and marine sediments because they provide rich, fertile habitats for food (e.g. fish, crustaceans, grains, fruit) and fiber (e.g. firewood, paper).

Soil biodiversity is also crucial to biologically control human, animal and plant pests and pathogens, flood and erosion, waste processing, soil fertility, and water purification.

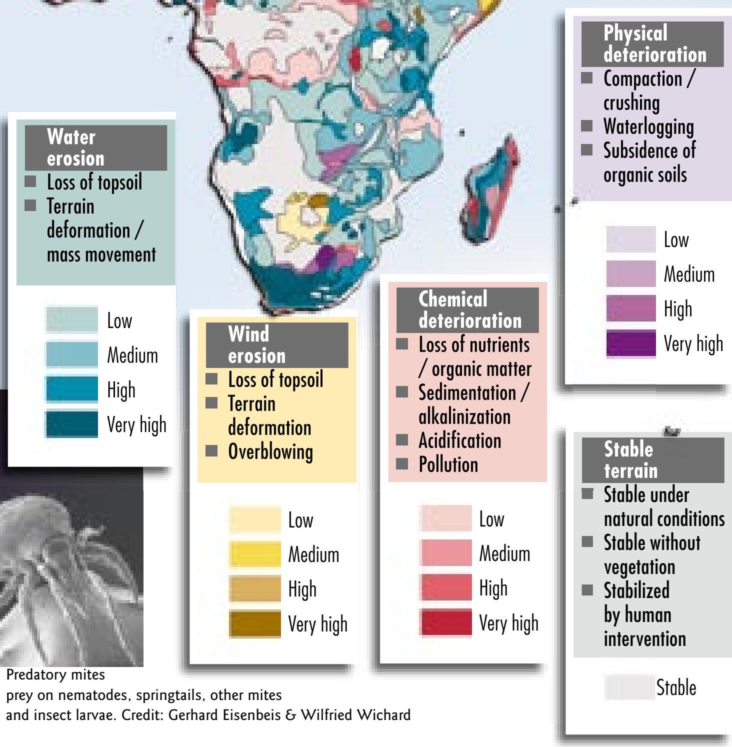
Soils and sediments are connected below and above surface



Soils and sediments, and the biodiversity they support, **are dynamic and non-renewa**

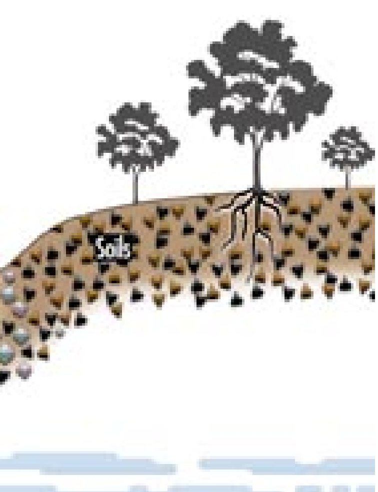


The Global Assessment of Human Induced Soil Degradation (GLASOD) of International Soil Reference and Information Centre (ISRIC). http://www.isric.org/



Predatory mites prey on nematodes, springtails, other mites and insect larvae. Credit: Gerhard Eisenbeis & Wilfried Wichard

There is increasing recognition that it is economically important to protect soils across landscapes and watersheds as source areas for drinking water. Reducing downstream transport of nutrients and sediments saves costly expenditure by industry, municipalities and consumers by reducing the costs of water treatment. Because the soil and sediment biodiversity metabolizes toxins and transforms harmful chemicals and excess nutrients, less chemical and filtration treatment is needed, resulting in higher quality of water at a lower cost.



Adapted from Wall, Diana H., ed. 2004. SCOPE 64.

Goods or service provided by soil and sediments and their biodiversity	What below-surface biodiversity does to enhance ecosystem processes
Food production	■ Living organisms rip, tear, eat, digest and decay organic matter, thus, act as a biotic fertilizer by returning nutrients to soil and sediments for plant and algae growth. ■ Their movement, burrowing or bioturbation aerates soils and sediments for increased growth of plants, animal and microbial species. ■ Their activity moves soil and sediment organic matter and carbon and nutrients into deeper layers, increasing soil and sediment fertility.
Water quality	■ Living organism biomass retains nitrogen (N). ■ Active movement of organisms mixes and creates structure leading to physical stabilization of soils and sediments, which decreases run-off and erosion of soils and sediments. ■ Organisms have a diversity of enzymes able to breakdown many pollutants by metabolic activity releasing water and CO_2 as end products.
Watershed flow	■ Hydrologic cycle is dependent on soil and sediment physical and biotic composition: organisms increase porosity, by their feeding and movement, and translocate organic matter which influences moisture retention.
Fiber production	■ Organisms increase nutrient cycling leading to soil fertility and biotic management of this fertility. ■ They provide biological controls and reduce the need for manufactured plant pathogen controls.
Carbon (C) sequestration	■ Organisms recycle nutrients by processing dead organic matter into less complex forms of carbon. ■ Their movement or bioturbation aerates soils and sediments for better growth of plants and animals and increases carbon storage and sequestration by clays and other particles of soil.
Trace gas/ nutrient regulation	■ The range of sizes and types of organisms, by their activity and metabolism, assist soils and sediments in maintaining C and N balances, as well as oxygenation.
Human, animal, plant health regulation	■ Soil and sediment organisms are part of foodwebs in which predators control pathogens and parasites. This biological control can be lost if soils and sediments are disturbed, leading to outbreaks of disease.

able natural resources that provide essential ecosystem services upon which above-grou

Oribatid mites are among the most numerous of the micro-arthropods. This millimeter-long species feeds on fungi. Credit: Gerhard Eisenbeis & Wilfried Wichard.

Global threats to soils and sediments

Despite the fundamental role played by soils and sediments for the Earth system and society, these cryptic below-surface habitats with their numerous species in complex foodwebs are being damaged at an unparalleled rate, affecting their ability to provide the services necessary for the sustainable functioning of all the Earth's ecosystems.

Disturbance, spread of invasive species, acidification of soils, increased nitrogen deposition and chemicals (pollutants, fertilizers and pesticides), and climate and land use change, severely and in some cases, irreversibly, impact soil and sediment communities and their ability to provide ecosystem services.

Habitat	Vulnerable taxa	Global threats	Ecosystem service at risk
SOIL			
Deserts	Algae, lichens, mosses, termites, ants, bacteria	Urbanization, aquifer depletion, invasive species, overgrazing, salinization, erosion	Decay, water filtration, soil stabilization
Tropical forests	Mycorrhizae, termites, ants, earthworms, mites, nematodes, fungi	Agricultural intensification, deforestation, invasive species	Soil fertility, decay, water filtration, carbon storage, soil aeration, soil stabilization and erosion control
Temperate forests	Earthworms, mites, fungi, ants, mycorrhizae	Acidification, agricultural intensification, deforestation, erosion, invasive species	Decay, water filtration, soil structure and stabilization, sediment trapping
Grasslands	Earthworms, enchytraeids, termites, nematodes, bacteria	Agriculture, overgrazing, urbanization, desertification	Herbivory, soil fertility, water filtration, carbon storage, pest control
Agro-ecosystems	Mycorrhizae, N-fixing bacteria, fungi	Deforestation, loss of soil organic matter, over-irrigation, erosion	Diminished soil quality, loss of productive soils
MARINE SEDIMENTS			
Estuaries	Bacteria, fish, macroinvertebrates	Pollution, invasive species, fisheries	Nutrient cycling, production, bioremediation, water filtration
Mangroves	Bacteria, plants, fish, macroinvertebrates	Habitat loss, pollution, invasive species	Nutrient cycling, production, shore stability and inland protection, sediment trapping, water filtration
Salt marshes	Bacteria, plants, fish, macroinvertebrates	Habitat loss, invasive species, pollution	Nutrient cycling, production, shore stability and inland protection, bioremediation, sediment trapping, water filtration
Coastal shelf	Bacteria, fish, macroinvertebrates	Fishing, habitat loss	Nutrient cycling, production
FRESHWATER SEDIMENTS			
Deep lakes	Fish, amphipods, gastropods	Pollution, overfishing, invasive species	Food production, nutrient storage
Shallow lakes	Fish, microbes, macrophytes	Acidification, overfishing, invasive species	Food production, nutrient cycling, sediment trapping
Rivers	Fish, mussels, microbes	Dams, levees, invasive species, pollution	Production, flood control, nutrient cycling, sediment transport, biofiltration
Reservoirs	Fish, mussels, microbes, decapods	Diversion, pollution, invasive species, overfishing	Production, flood control, nutrient cycling, sediment transport, biofiltration
Springs	Microbes, macrofauna	Pollution, diversion	Water supply
Ponds and wetlands	Macrophytes, invertebrates	Land use, invasive species	Nutrient cycling, flood control
Groundwater	Microbes	Diversion	Water supply, water filtration

Soils and sediments are natural resources that once damaged often retain a long-term legacy of mismanagement. Their slow recovery increases the urgency for better understanding of how best to manage and conserve below-surface biodiversity. Timing is critical because these unseen and unappreciated organisms are threatened globally by human activity.

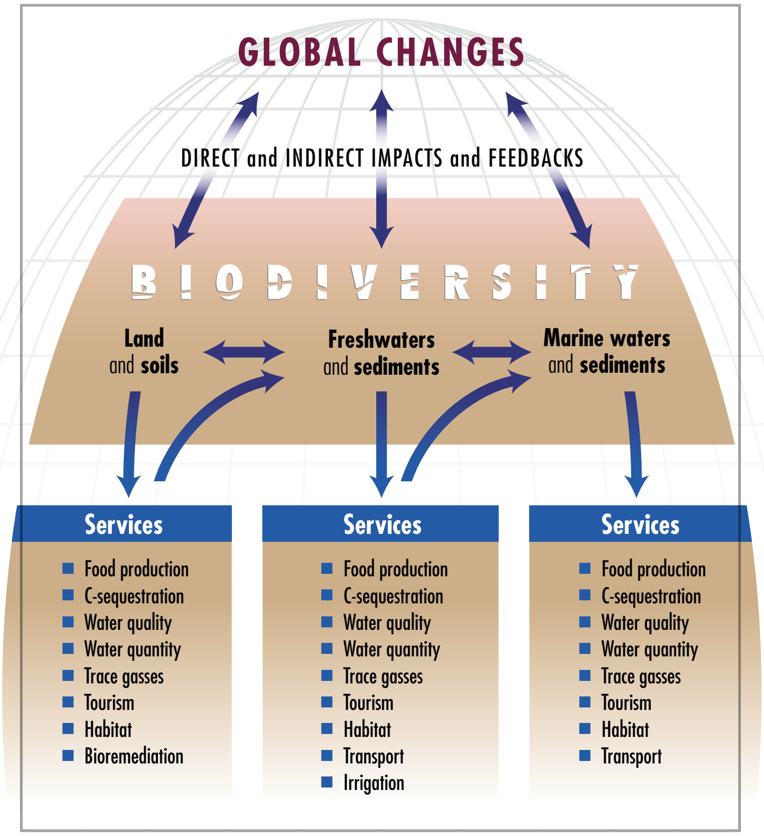
Emerging challenges as a result of global changes will place new demands on soils and sediments and their biodiversity, because these species are intimately tied to societal use of lands, freshwaters and oceans.

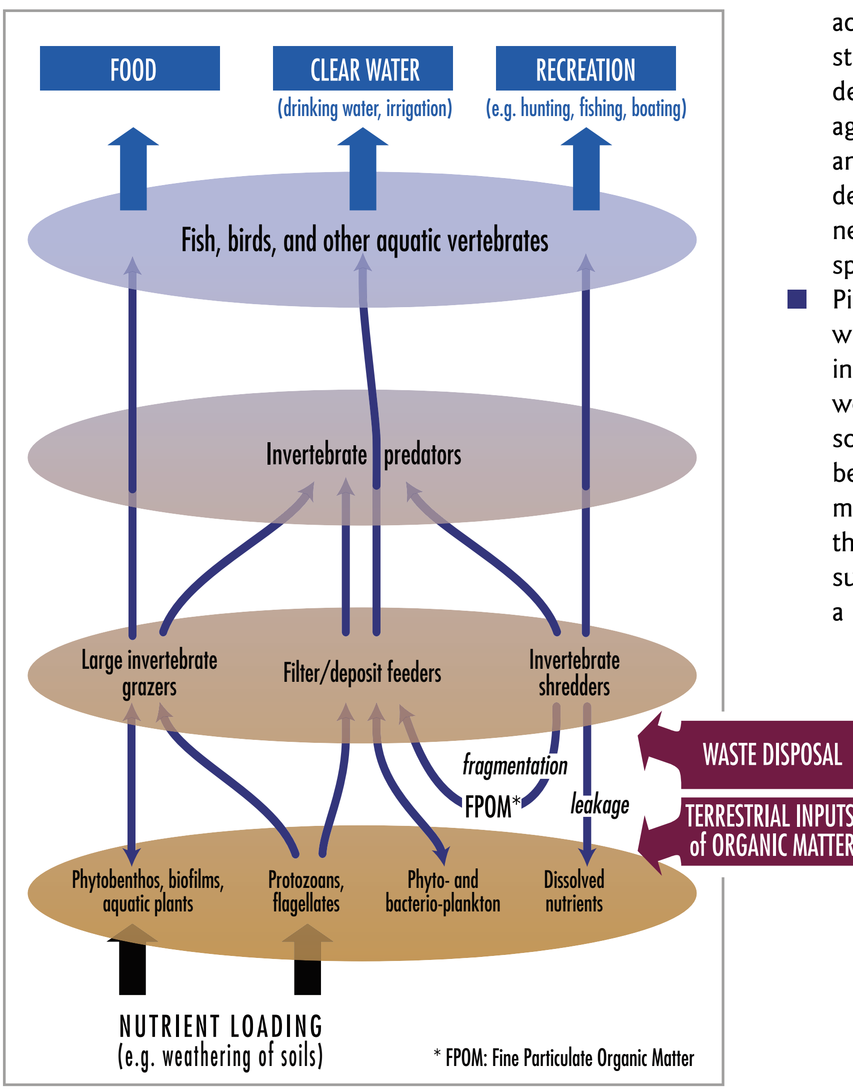
Evidence shows that biodiversity of soils and sediments is significantly altered by, and is vulnerable to, many types of global changes affecting lands and waters:

- Intensive agriculture, urbanization, deforestation, drought, desertification,
- Seabed trawling, overfishing and removal of top predators, dredging, damming and channelizing of rivers, intensive aquaculture,
- Changes in atmospheric composition (increase in CO_2 and available fixed nitrogen) and aquatic composition (pH, nitrogen loading),
- Climate change, and
- Pollution such as eutrophication and acidification.

In addition to soils and sediments being major sinks for sequestering carbon, their disruption, through plowing or trawling, releases CO_2 to the atmosphere. Certainly, any new venture to sequester carbon in soils and sediments, or to develop alternative energy such as biofuels, will need to include careful management of the connections among soil and sediment habitats.

und terrestrial and aquatic ecosystems depend.





Ensuring sustainability of soil and sediment biodiversity

Since the living biodiversity of soils and sediments is an important component of all ecosystems undergoing global changes, restoration, management and policy options focused at the following are critical to understanding sustainability at the country level:

Biodiversity of soils and sediments

- Focus on managing natural biodiversity in soils and sediments.
- Include management options for agriculture that maximize biotic regulation and sustainable soil and sediment fertility.
- Incorporate knowledge of conservation, protection and remediation of our most productive soils and sediments to establish sustainable management options.

Below- and above-surface connections

- Consider soils, freshwater and marine sediments as continuous ecosystems supporting life above and below surface. When excess fertilizers are applied, the role of soil biodiversity – to cycle nutrients and enhance soil fertility – is bypassed. High nutrient concentrations contribute to the death of these below-surface and other organisms. The accumulation of nutrients and soil flushed from land into streams and rivers causes death of sediment organisms, degrades breeding habitats for fish and shellfish, and aggravates aquatic biodiversity die off. The formation and spread of a 'dead zone' along coastal areas, where dead organic materials decompose and use up oxygen needed for coastal foodwebs, including bottom-dwelling species, exacerbates the decline of fisheries.
- Piecemeal, sectoral approaches should be replaced by whole-system approaches that consider the full watershed, including soil and sediment biodiversity and functions as well as their cascade of interactions and impacts. When scientists and managers work only in distinct above- or below-surface domains (soil or freshwater or marine sediments), this isolation and lack of coordination disregards the connections of the below-surface organisms and results in additional problems that could be avoided with a holistic approach to management.

Research

- Establish long-term, integrated, global experiments across soil and sediment communities to determine how biodiversity or surrogates of below-surface communities contribute to ecosystem processes and sustain ecosystem services.
- Include knowledge of linked soil and sediment processes to improve global and regional carbon, water and nutrient models of global changes.

Way forward

Improving the management of below-surface biodiversity:

Actions for the future

- **Soils and sediments** and their biodiversity cannot be easily sustained in the future without a major coordinated effort involving integration of multiple disciplines and a combination of theory, rigorous hypothesis testing, long-term experiments and involvement of scientists and stakeholders in establishing best management practices.
- **Attention to sustainable management** of soil and sediment biodiversity is urgently needed.
- **Recommended actions** to manage this biodiversity could ensure ecosystem services for the long term.

Functions of Living Soils and Sediments	Ecosystem Processes Supported by Biodiversity	Recommended Actions	Effects
Sequester Carbon (soils and sediments are major sinks of carbon)	■ Organic matter formation, inorganic carbon deposition	■ Wise management of cultivation ■ Reduce trawling and dredging	■ Reduces CO_2 emissions and damage to above- and below-surface habitats
Detoxify Waters	■ N retention in biomass, physical stabilization, interception of runoff, pollutant metabolism and organic matter decomposition	■ Better timed and measured application of fertilizers and pesticides ■ Crop rotations	■ Cleaner water supplies ■ Decreased costs in water treatment ■ Increased health of fish and shellfish
Maintain Soil Fertility	■ Decomposition, bioturbation, organic matter formation, nutrient cycling	■ Implementation of best-practice cultivation ■ Management of soil biodiversity and biocontrol of plant pathogens and pests	■ Sustainable use of productive land ■ Continued yield of food and fiber
Facilitate Waste Management	■ Decomposition, detoxifying pollutants	■ Wise waste disposal practices on land and waters ■ Reduce concentrations of animals and their wastes (including fish and shrimp farms and farm animals)	■ Dispersal of waste aids retention of soil and sediment and decomposition of wastes ■ Decreased toxicity and pollution of disposed waste

Cover photos (from top)
Nematodes *Cervidellus doorselaeri* and *Chiloplacus* sp., both bacterial feeders.
Credit: Manuel Mundo-Ocampo
Giant millipede, *Orthoporus ornatus*.
Credit: David B. Richman.

Readings

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Useful links

Biological Soil Crusts: http://www.soilcrust.org/gallery.htm
FAO Soil Biodiversity and Agricultural Context: http://www.fao.org/ag/agl/agll/soilbiod/fao.stm
Horizons in Soil Research workshop : http://www.iger.bbsrc.ac.uk/SRACWorkshop/
Island Press: http://www.islandpress.org
ISRIC World Soil Information : http://www.isric.org/
Landcare Research Soil Vulnerability Maps: www.landcareresearch.co.nz/research/rurallanduse/soilquality/vulnerability_maps.asp
Long-Term Soil-Ecosystem Studies: http://ltse.env.duke.edu/
Natural Resource Ecology Soil Biodiversity and Ecosystem Function Lab: http://www.nrel.colostate.edu/projects/soil/
NERC (UK)Biological Diversity and Ecosystem Function in Soil: http://soilbio.nerc.ac.uk/
Scientific Committee on Problems of the Environment (SCOPE): http://www.icsu-scope.org
Tropical Soil Biology and Fertility (TSBF) Institute: http://www.ciat.cgiar.org/tsbf_institute/
UNESCO: http://www.unesco.org
University of Wisconsin - Soil Health and Biodiversity: http://www.cias.wisc.edu/wicst/research/coretriol/soil.htm
USDA Soils Maps: http://soils.usda.gov/use/worldsoils/mapindex/

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